IMPROVED THREE-DIMENSIONAL VELOCITY MODELS AND EARTHQUAKE LOCATIONS FOR CALIFORNIA

External Grant Award Number 05HQGR0067

Clifford H. Thurber
Department of Geology and Geophysics,
University of Wisconsin-Madison, Madison, WI 53706

Telephone: (608) 262-6027; FAX: (608) 262-0693; email: thurber@geology.wisc.edu

Investigations Undertaken

Our work focuses on the development of three-dimensional (3-D) seismic wavespeed models for the greater San Francisco (SF) Bay Area and for the majority of northern California. The model will be used by others to compute strong ground motions in a simulation of the 1906 event, in preparation for the centennial of the great 1906 San Francisco earthquake, and it will help to characterize both well-known and hidden seismogenic structures. The datasets for the SF Bay and northern California models combine P-wave arrival times from well-distributed sets of about 6,000 and 4,000 earthquakes, respectively, with a complete archive of available active-source (explosion) P-wave travel times from the region. The wavespeed modeling is being carried out with a combination of conventional and "double-difference" seismic tomography.

We have worked in collaboration with Tom Brocher of the USGS to assemble a quality-controlled active-source dataset that is as complete as possible for northern California, including some data that have never been utilized previously for seismic tomography (Figure 1). We have also extracted catalog phase arrivals for some of the larger shots recorded at the NCSN stations. That effort is complete, including cross-checking of source and receiver coordinates, verification of valid travel time curves and receiver name rationalization across all experiments (plus the NCSN).

In parallel, we have extracted arrival time data for earthquakes that are optimally distributed throughout the two study regions. We have compiled and merged all of these data and carried out preliminary "conventional" tomography analyses using simul2000 [Thurber and Eberhart-Phillips, 1999], followed by double-difference (DD) tomography [Zhang and Thurber, 2003]. Examples of our tomography results for the two regions are presented below. Work on a manuscript on the SF Bay results is nearing completion.

Results

The model grid for the SF Bay inversion has 5 to 10 km spacing in the horizontal directions, whereas for the northern California model it is 10 to 20 km. Both models use grid intervals of 1 to 5 km in the vertical direction, gradually increasing with depth. We use a one-dimensional model from Hole et al. [2000] as our starting model. Smoothing weighting constraints on the horizontal and vertical directions were applied to the model, with the weighting values based on testing a range of smoothing parameters. During the inversion, the inversion grid nodes whose derivative weight sum (an approximate measure of resolution) values were smaller than 20 were kept fixed to help control the stability of the inversion. Residual weighting and distance weighting were also applied. Our new model provides the first regional view of several basement highs, defined by wavespeed anomaly highs, that are imaged in the uppermost few kilometers of the model. Recognition of these known geologic features in the tomography model gives us confidence in the accuracy of the model. Our model also images a number of wavespeed anomaly lows associated with known Mesozoic and Cenozoic basins in the study area.

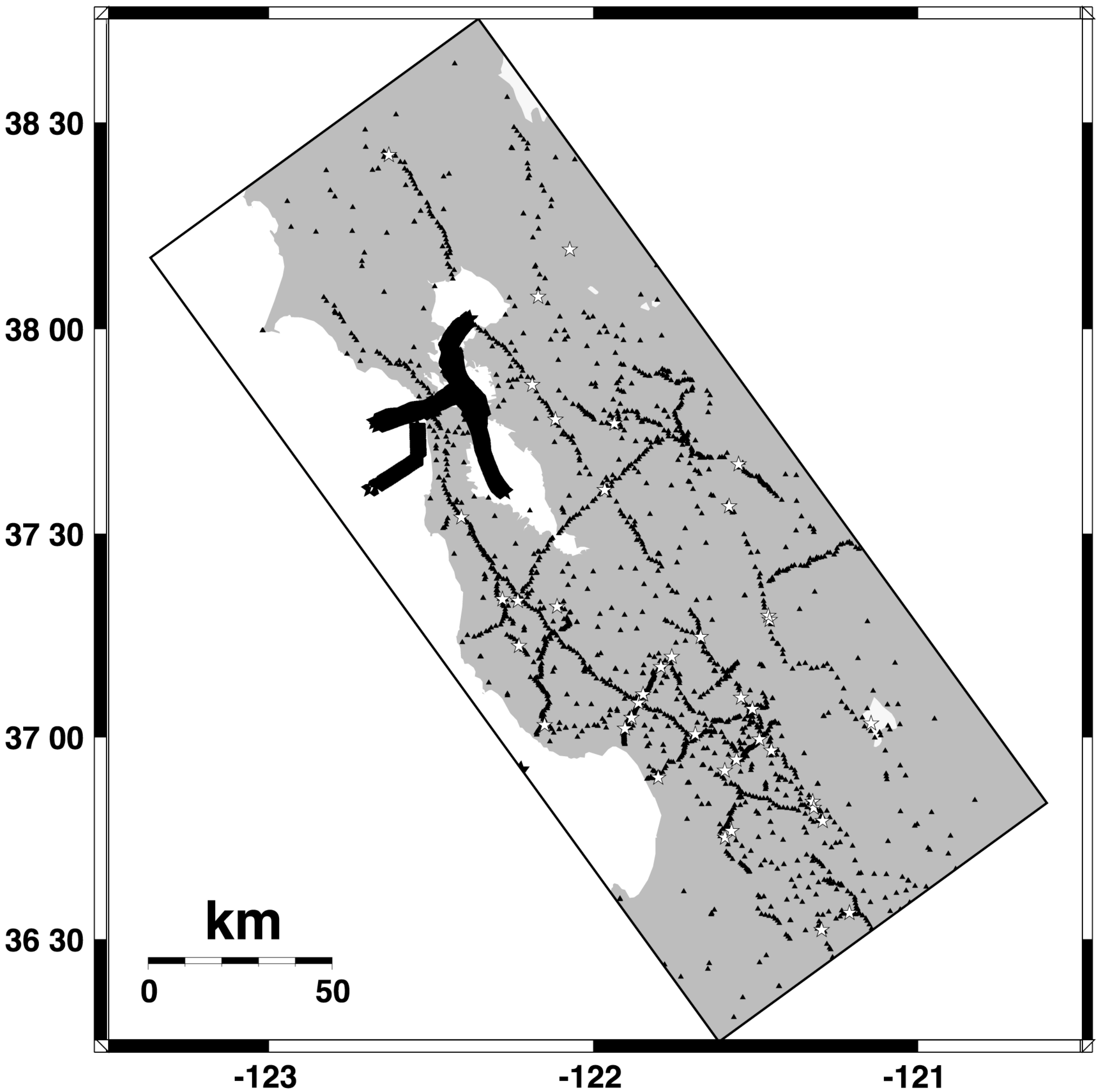

Figure 1. Map of the shots (stars) and receivers (triangles) used for our SF Bay model.

The SF Bay model covers the region west of the Great Valley from Hollister to Clear Lake (Figures 1 and 2). The geometries of the major faults are clearly defined by the relocated seismicity (Figures 2 and 3), and many of the seismogenic faults are marked by significant wavespeed features (Figure 3). Where the models overlap, our results are quite similar to those of Thurber [1983], Dorbath et al. [1996], and Eberhart-Phillips et al [1998], among others, although in general our resolution of structure appears to be significantly improved. We attribute the improvement to the increased size of the dataset, the use of differential time data, and the abundance of active-source data we have been able to incorporate.

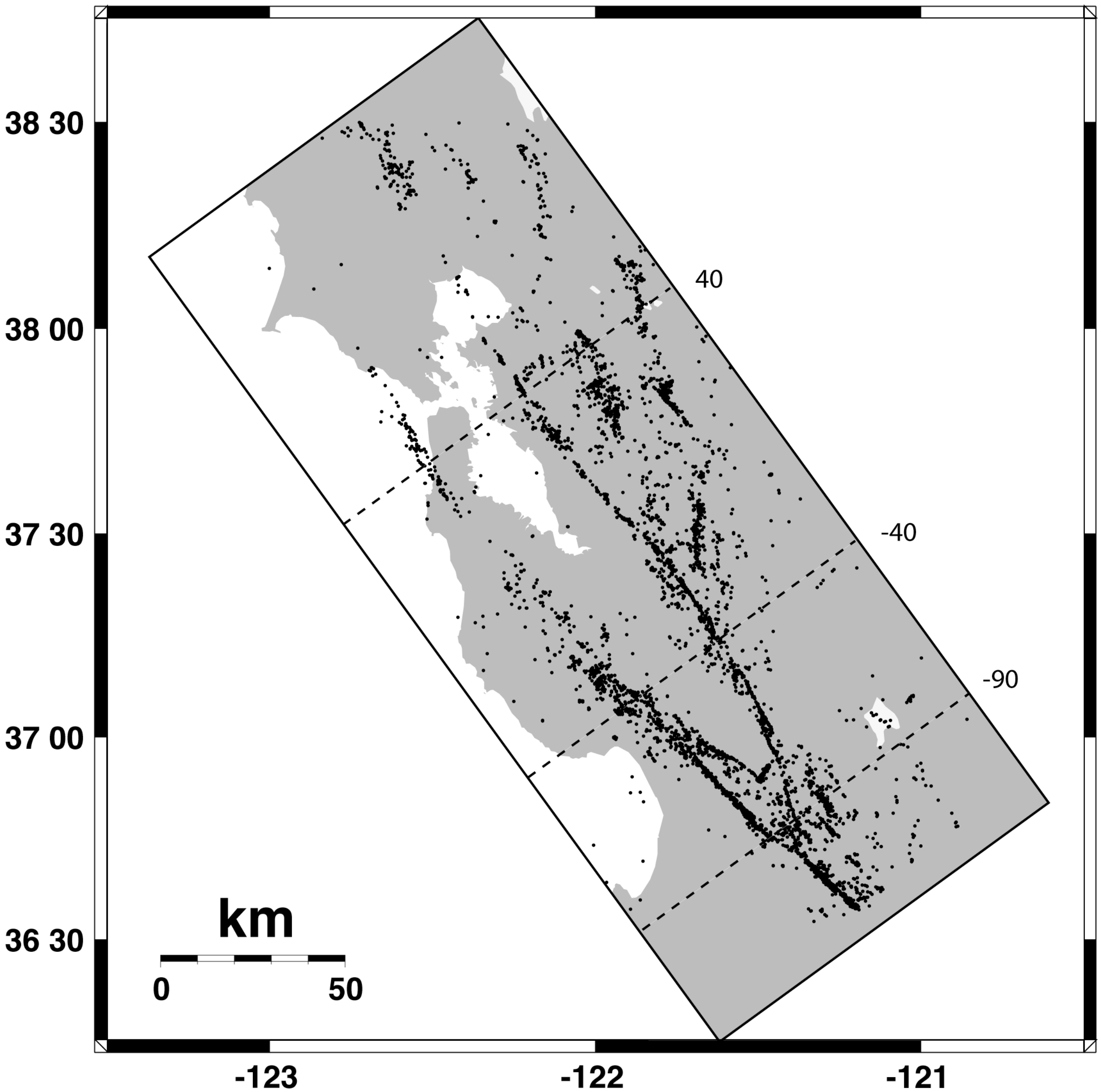

Figure 2. Map of the earthquakes (circles) used for our SF Bay model. Model cross-sections along the indicated profiles are shown below in Figure 3.

Figure 3 shows example cross-sections through our 3-D SF Bay model. In the Y=-90 km section (top), the main faults apparent in the seismicity, from southwest to northeast, are the San Andreas (km -10), Paicines (km 0), and Ortigalita (km 10). In the Y=-40 km section (middle), the main faults are the San Andreas/Loma Prieta (km -20) and Calaveras (km 10). In the Y=40 km section (bottom), the main faults are the San Andreas (km -25), Hayward (km 5), and Vacaville-Kirby Hills (km 30). We also note the seismically active ramp-like structure between km 40-50 that apparently is a reverse fault near the edge of the Great Valley.

The SF Bay model is relatively well resolved except around the model edges, but it does not span a region large enough for full modeling simulations of the 1906 rupture. Thus we expanded our model region to cover an area of about 400 km by 650 km, centered on 39° N, 121° W. Figure 4 shows the shots, receivers, and earthquakes included in our northern California model. We used fewer earthquakes than for the SF Bay model, even though this is a larger region, because we selected only the larger earthquakes in order to assure high-quality picks out to greater epicentral distances. We will endeavor to improve the results by incorporating stations and picks from the Nevada network in the eastern part of the model, and possibly University of Washington data from the Klamath Lakes area in the northern part.

An example map-view slice through the 3-D model at 6 km depth is shown in Figure 5. At this scale, the structure of individual fault zones is not evident. However, we can see low velocities (orange colors) just east of the main belts of seismicity (X = ~0 to -50) indicating thick sediments on the western edge of the Great Valley, with higher velocity bedrock of the Sierra Nevada and Coast Ranges on either side. The offshore-onshore data from the Mendocino Triple Junction experiment allow us to image the Eel River Basin (X = -100 km, Y = 250 to 300 km). At greater depth (20 to 35 km), our model images the top of the subducting Gorda Plate north of the Mendocino Triple Junction, inland from the Eel River Basin (Figure 6, X = 50 to -50 km, Y = ~200 to 250 km). A second deep zone of seismicity near the western edge of the Sierra Nevada (Figure 6, X = 0 to 100 km, Y = ~0 to 200 km) is associated with a "tongue" of high velocity material. These two zones are separated by a zone of lower velocity, indicating the two are not directly related, contrary to the suggestion of Hill et al. (1990).

We will complete our effort for 2005 by finishing our manuscript on the SF Bay 3-D model and its interpretation, and by updating the northern California model following some quality-control work and the addition of available data to fill in gaps.

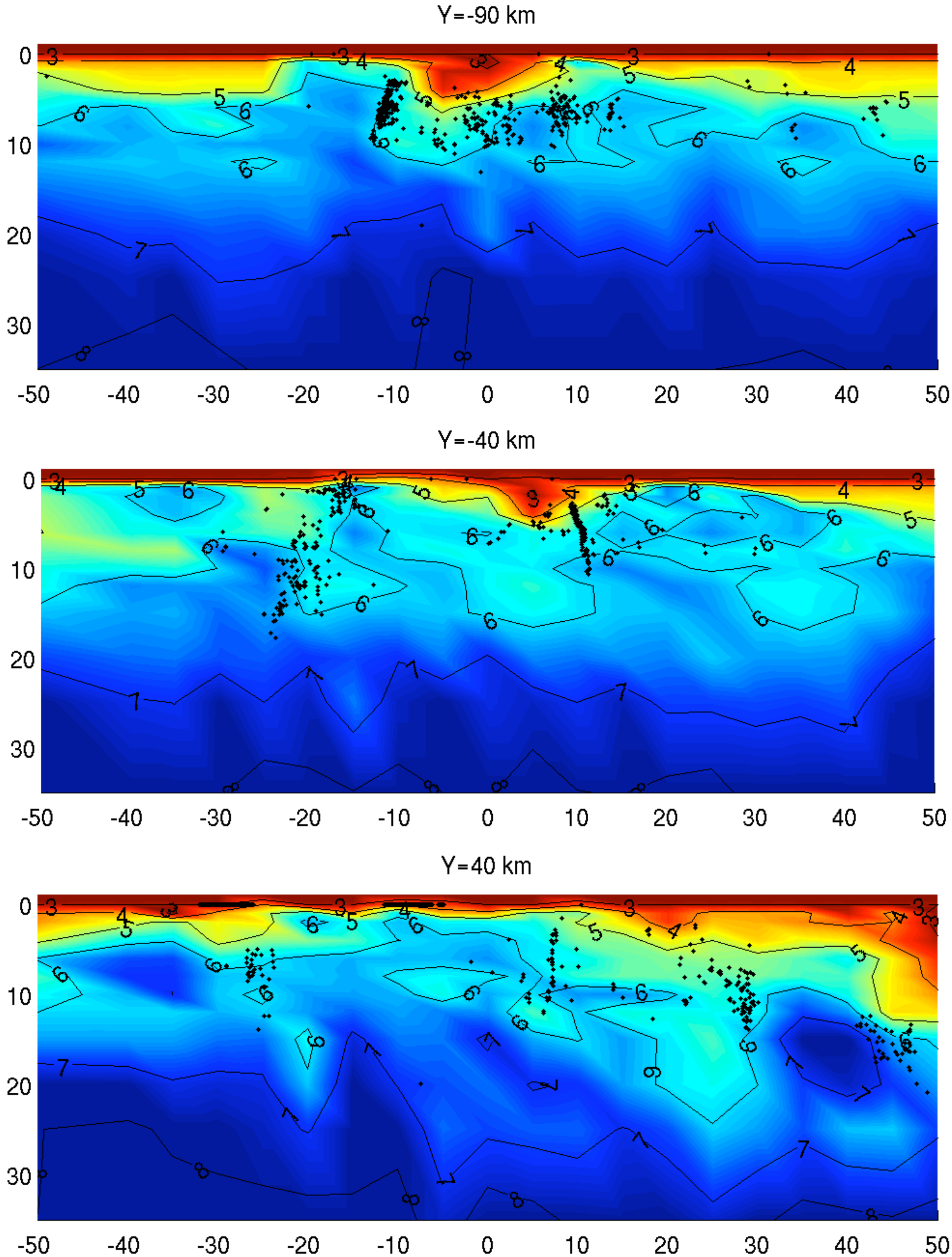

Figure 3. Cross-sections through the SF Bay P-wavespeed model along the profiles indicated in Figure 2. Earthquake hypocenters within 5 km of the section are indicated by circles.

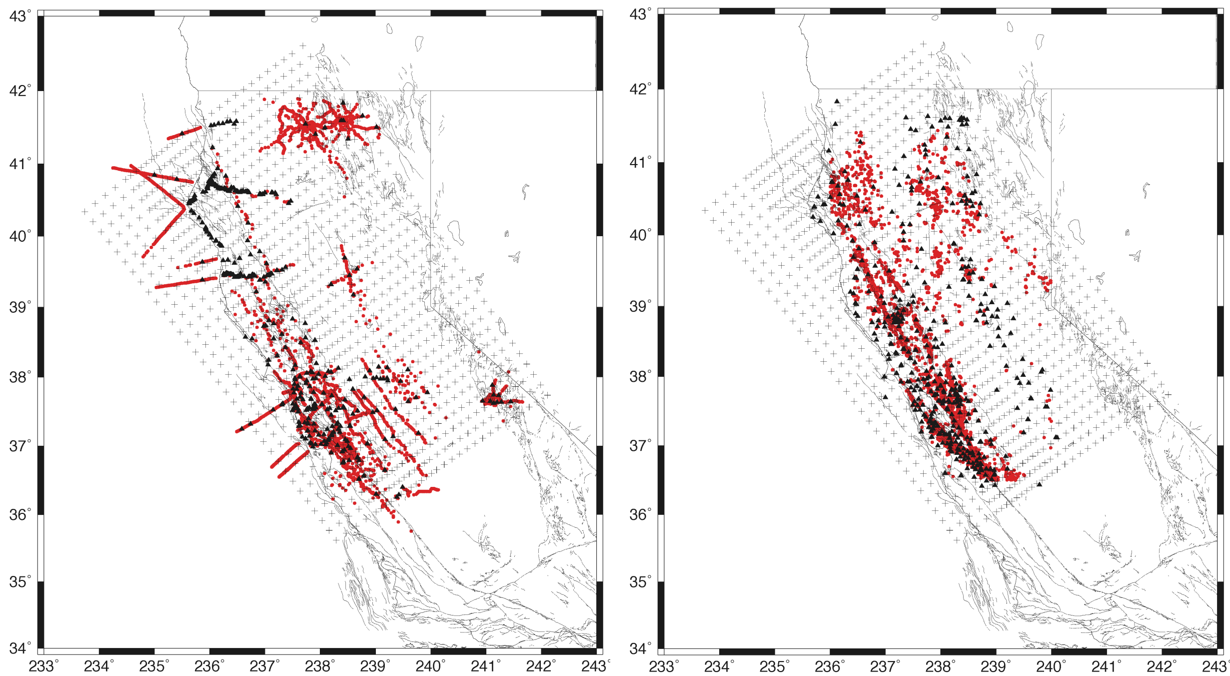

Figure 4. Maps of the active sources and receivers (left) and earthquakes and network stations (right) used for our northern California model. Note that some sources and receivers have been "interchanged" for efficiency purposes, which is justified by reciprocity.

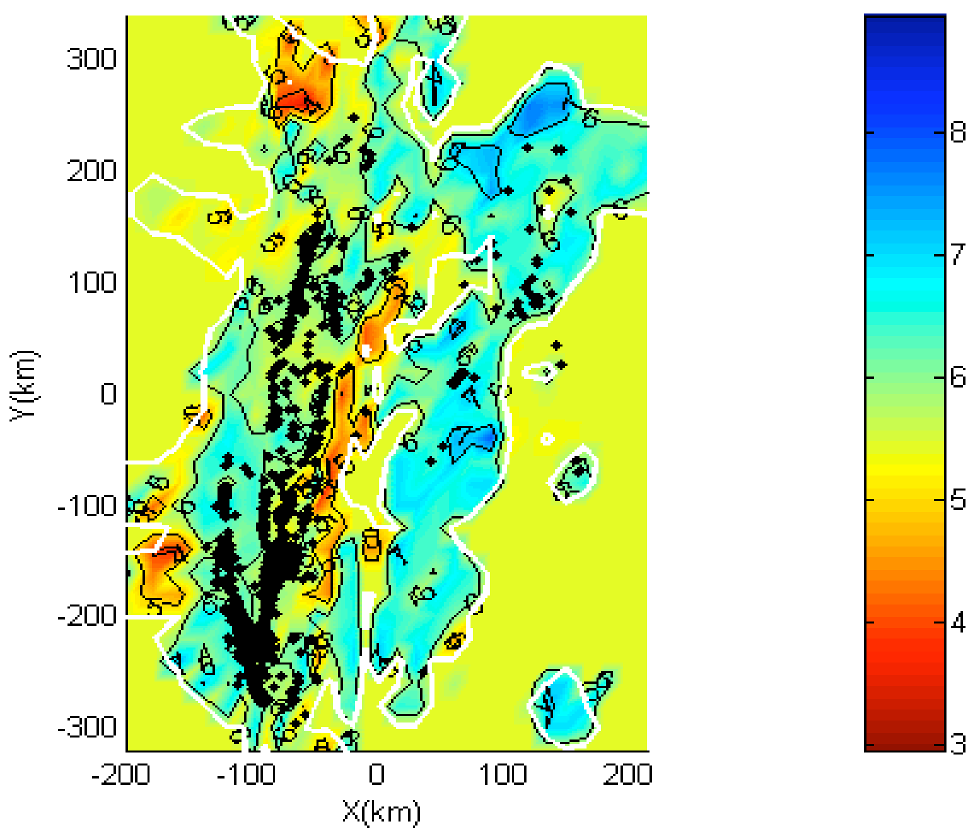

Figure 5. Example map-view slice through the northern California model at 6 km depth.

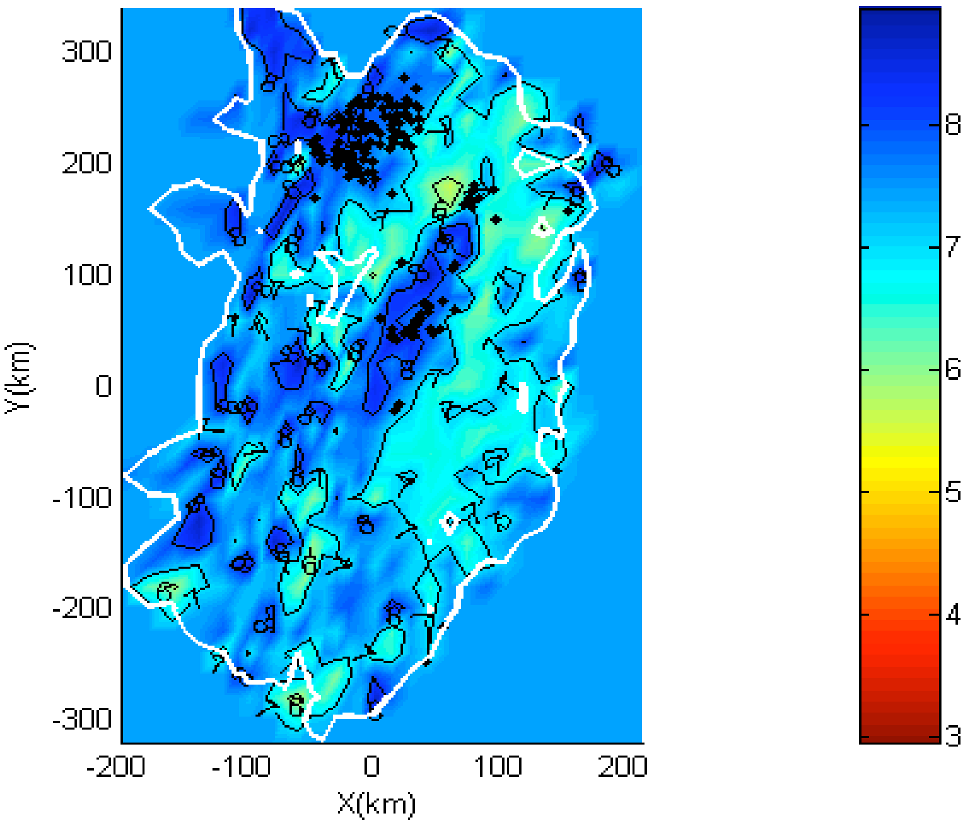

Figure 6. Example map-view slice through the northern California model at 25 km depth.

References

Dorbath, C., D.H. Oppenheimer, F. Amelung, and G.C.P. King, Seismic tomography and deformation modeling of the junction of the San Andreas and Calaveras faults, *J. Geophys. Res*. *101*, 27,917. 1996.

Eberhart-Phillips, D., and A.J. Michael, Seismotectonics of the Loma Prieta, California, region determined from three-dimensional Vp, Vp/Vs, and seismicity, *J. Geophys. Res*. *103*, 21,099, 1998.

Hill, D. P., J. P. Eaton, and L. M. Jones, Seismicity, 1980-86, in *The San Andreas Fault System, California*, U.S.G.S. Prof. Paper 1515, 115-151, 1990.

Hole, J. A., T.M. Brocher, S.L. Klemperer, T. Parsons, H.M. Benz, and K.P. Furlong, Three-dimensional seismic velocity structure of the San Francisco Bay area, *J. Geophys. Res. 105*, 13,859, 2000.

Thurber, C.H., Earthquake locations and three-dimensional crustal structure in the Coyote Lake area, central California, *J. Geophys. Res.*, *88*, 8226, 1983.

Thurber, C., and D. Eberhart-Phillips, Local earthquake tomography with flexible gridding, *Comp. & Geosci.*, *25*, 809, 1999.

Zhang, H., and C.H. Thurber, Double-difference tomography: method and application to the Hayward fault, California, *Bull. Seismol. Soc. Am.*, *93* 1875, 2003.

Non-technical Summary

In preparation for the centennial of the great 1906 San Francisco earthquake, we have developed regional three-dimensional seismic wavespeed models for Northern California. The models will be used by others to compute strong ground motions in a simulation of the 1906 event, and they will help to characterize the geometry of both well-known and hidden seismogenic structures. The dataset combines P-wave arrival times from thousands of earthquakes with a complete archive of available active-source (explosion) P-wave travel times from the region. The wavespeed modeling was carried out with a combination of conventional and "double-difference" seismic tomography.

Reports Published

Thurber, C., H. Zhang, V. Langenheim, and T. Brocher, Geophysical characterization of seismogenic structures in northern California, Eos Trans. AGU, 85(47), Fall Meet. Suppl., Abstract S51D-01, 2004.

Availability of Results

We have submitted our 3-D models to Tom Brocher of the U.S.G.S. for use in development of the 3-D geologic model of northern California. Contact person: Clifford Thurber (608-262-6027; thurber@geology.wisc.edu). Format: tab-delimited table.